The Impacts of Ionospheric Space Weather

An applied research perspective OR

"How to condense 20 years of applied space weather research into 15 minutes"

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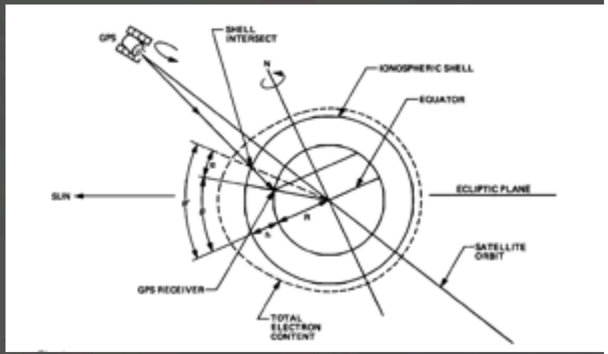
Xiaoqing Pi
Olga Verkhoglyadova
Brian Wilson
Lawrence Sparks
Mark Butala
Tom Runge
Byron Iijima
Vardan Akopian



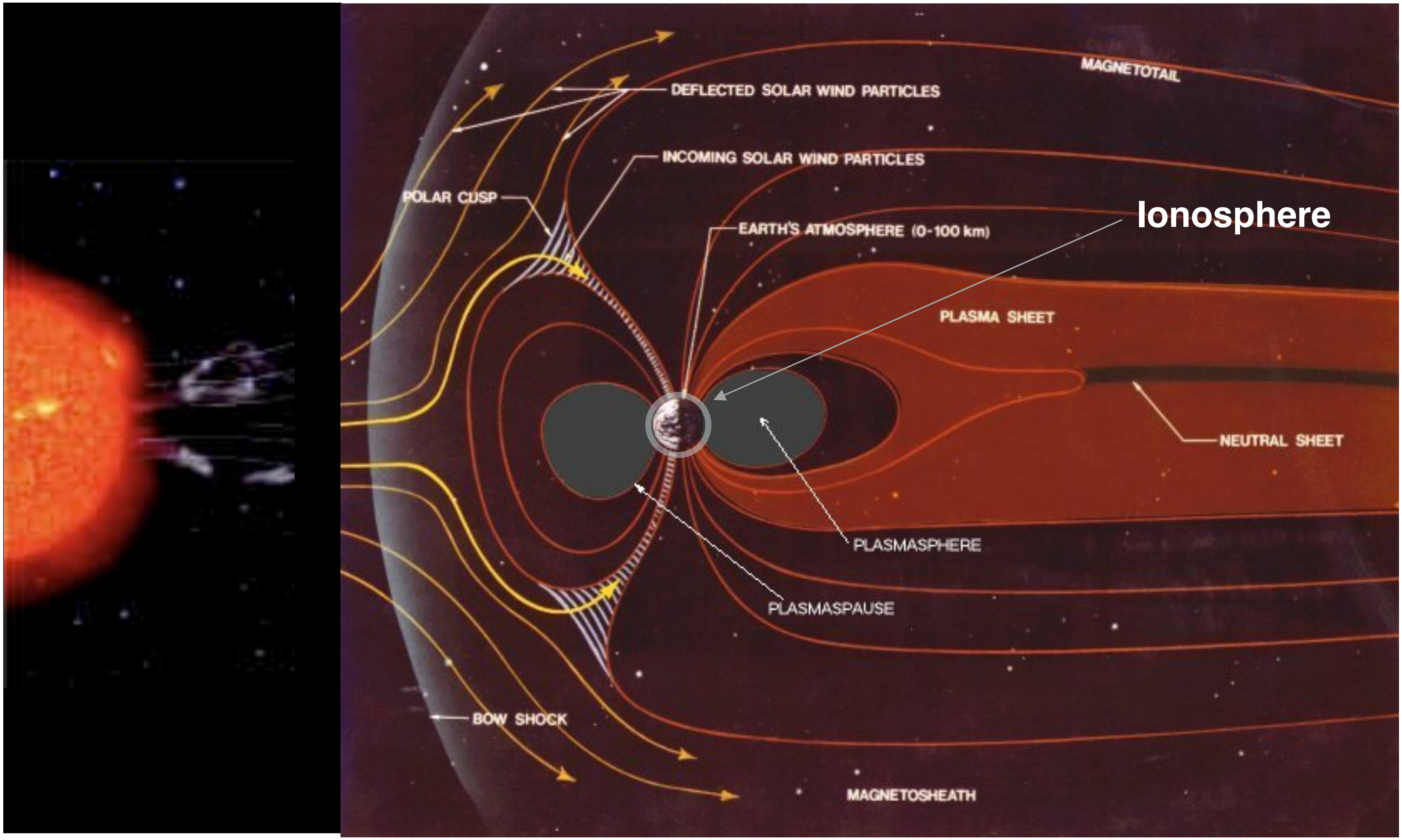
From Lanyi and Roth
Radio Science, 1988

Collaborator at University of Southern California:
Prof Chunming Wang

Overview

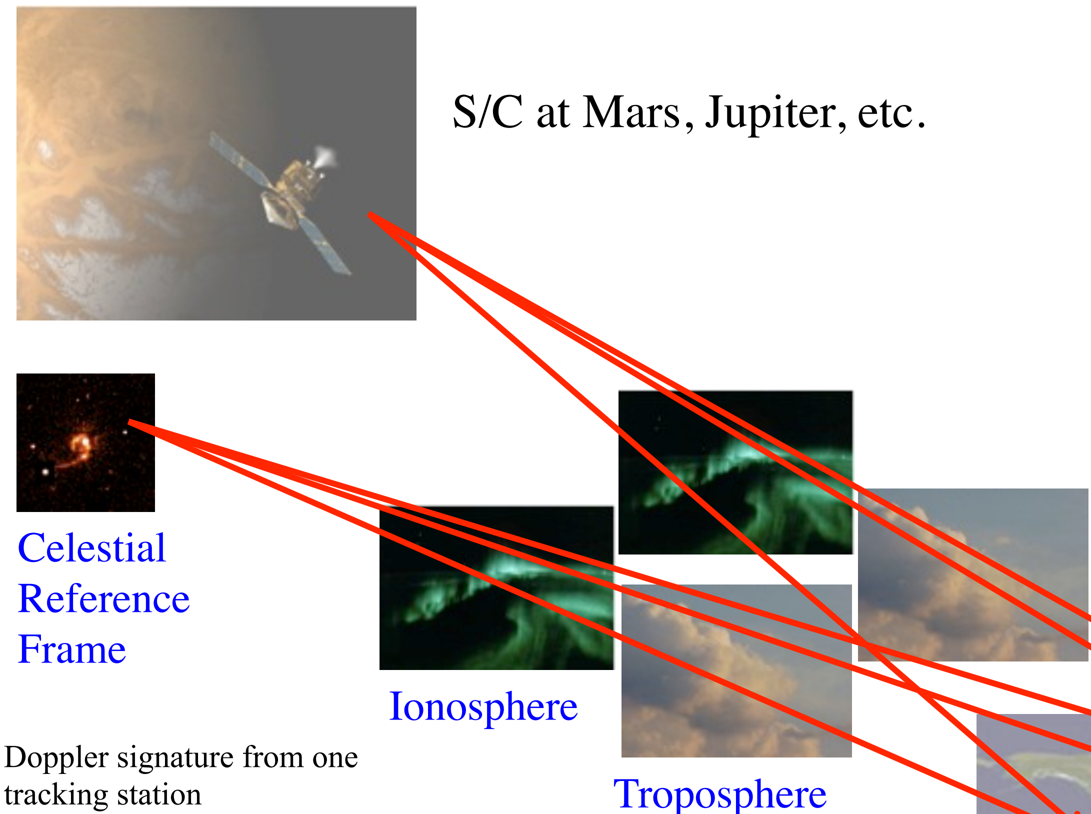
- Navigation, Radar, Communications
- The fundamental issue: variability
- Applications
- Solutions

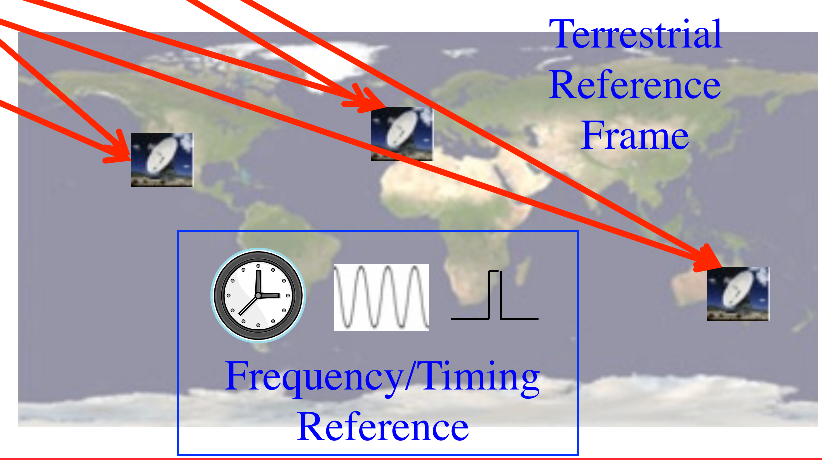
Regions In Geospace: Ionosphere is Near-Earth Space



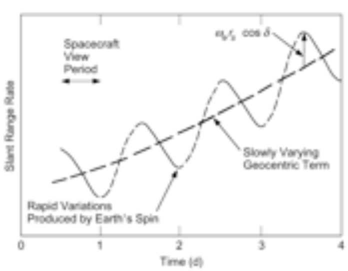
Deep Space Navigation: An Application of Space Weather Research

- Angular accuracy requirement
  - 0.12 μrad
  - 24 milliarcsec
- Time for Earth to rotate 0.12 μrad is 1.6 millisec
- Distance precision over one Earth radius: 0.75 m



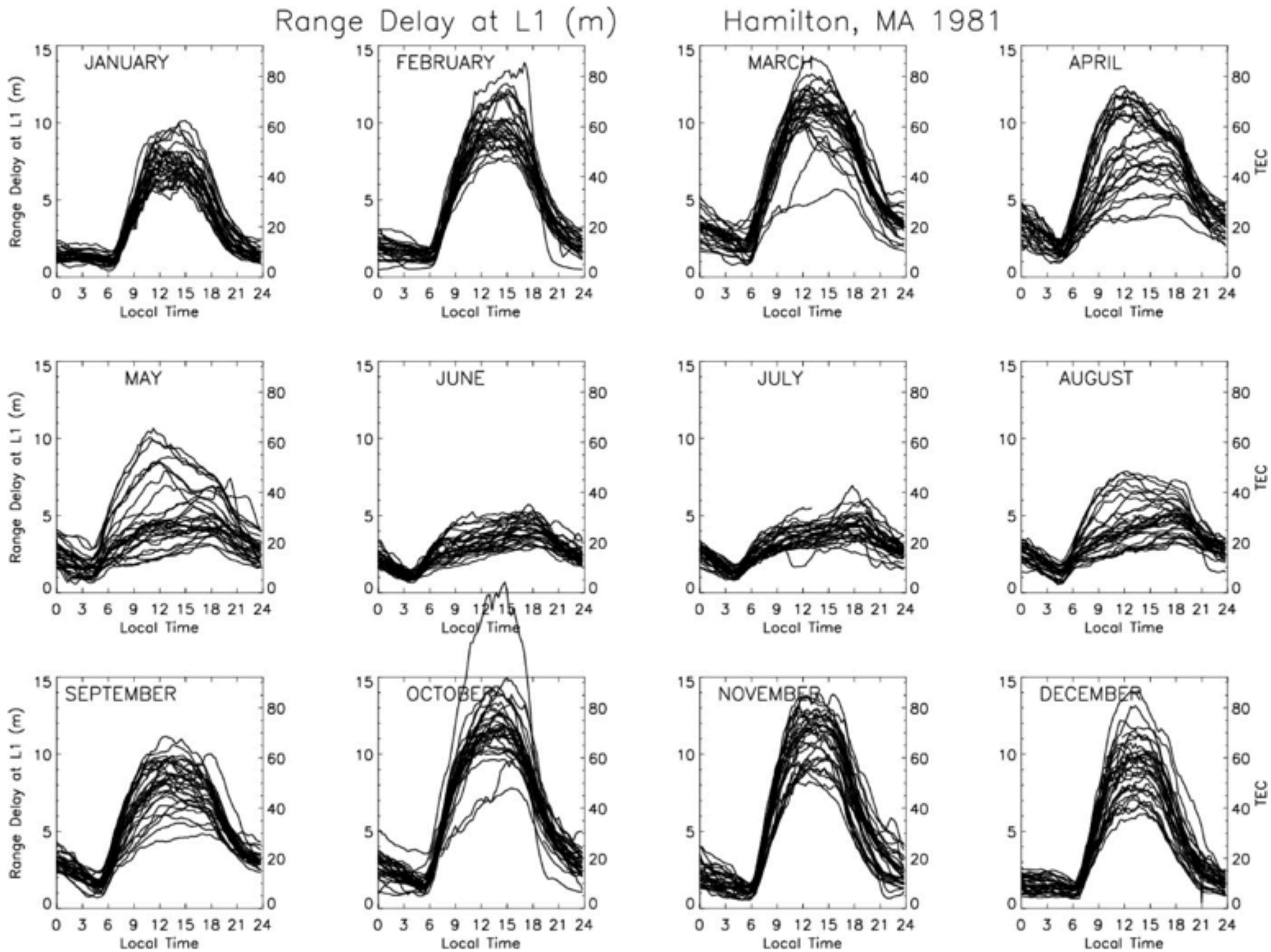


Doppler signature from one tracking station



δ is spacecraft declination

Day-to-Day Variability



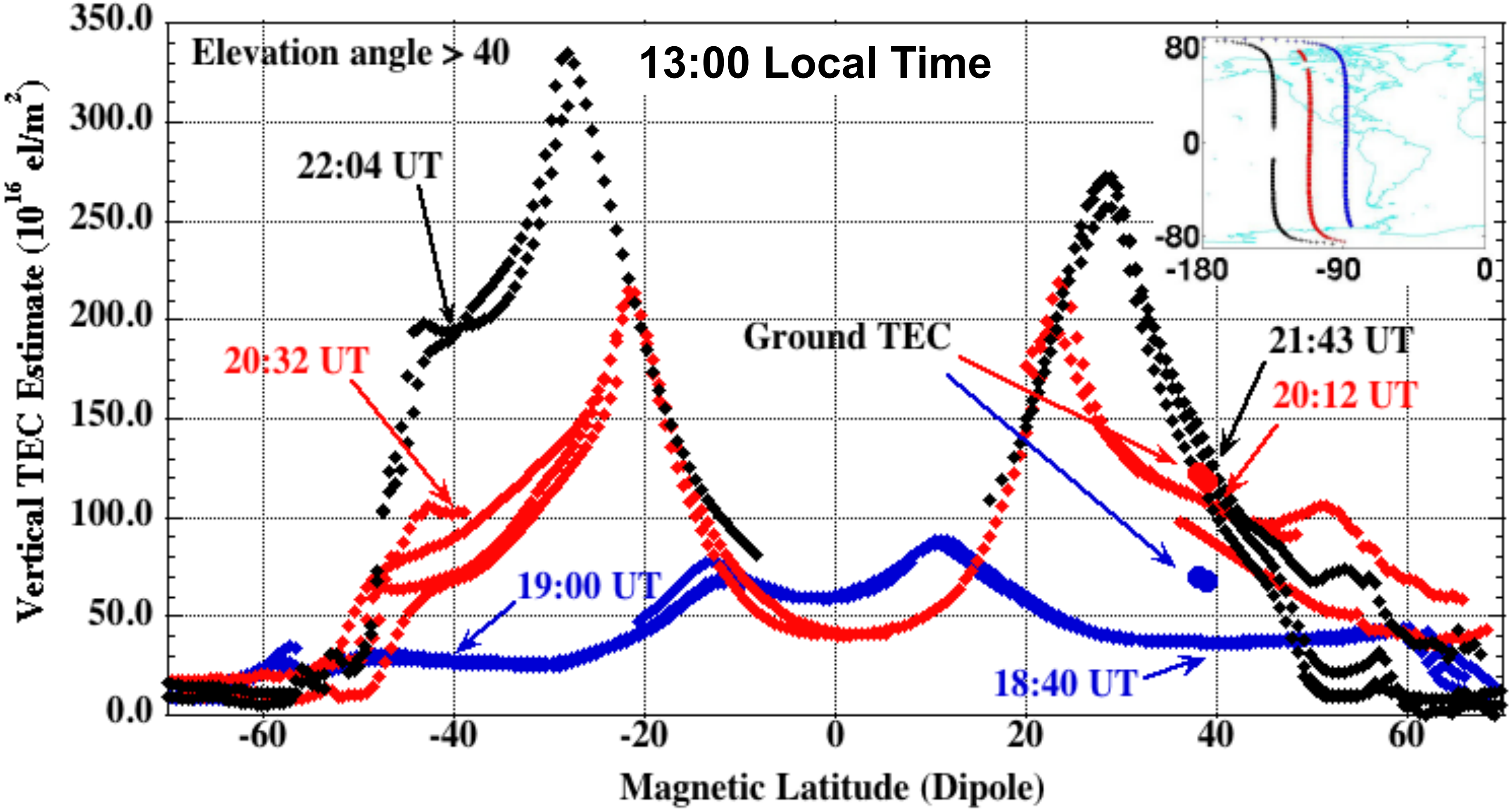
"Slant range"

Requirement:

Meet this everywhere, all the time

Variability During Geomagnetic Storms October 30, 2003

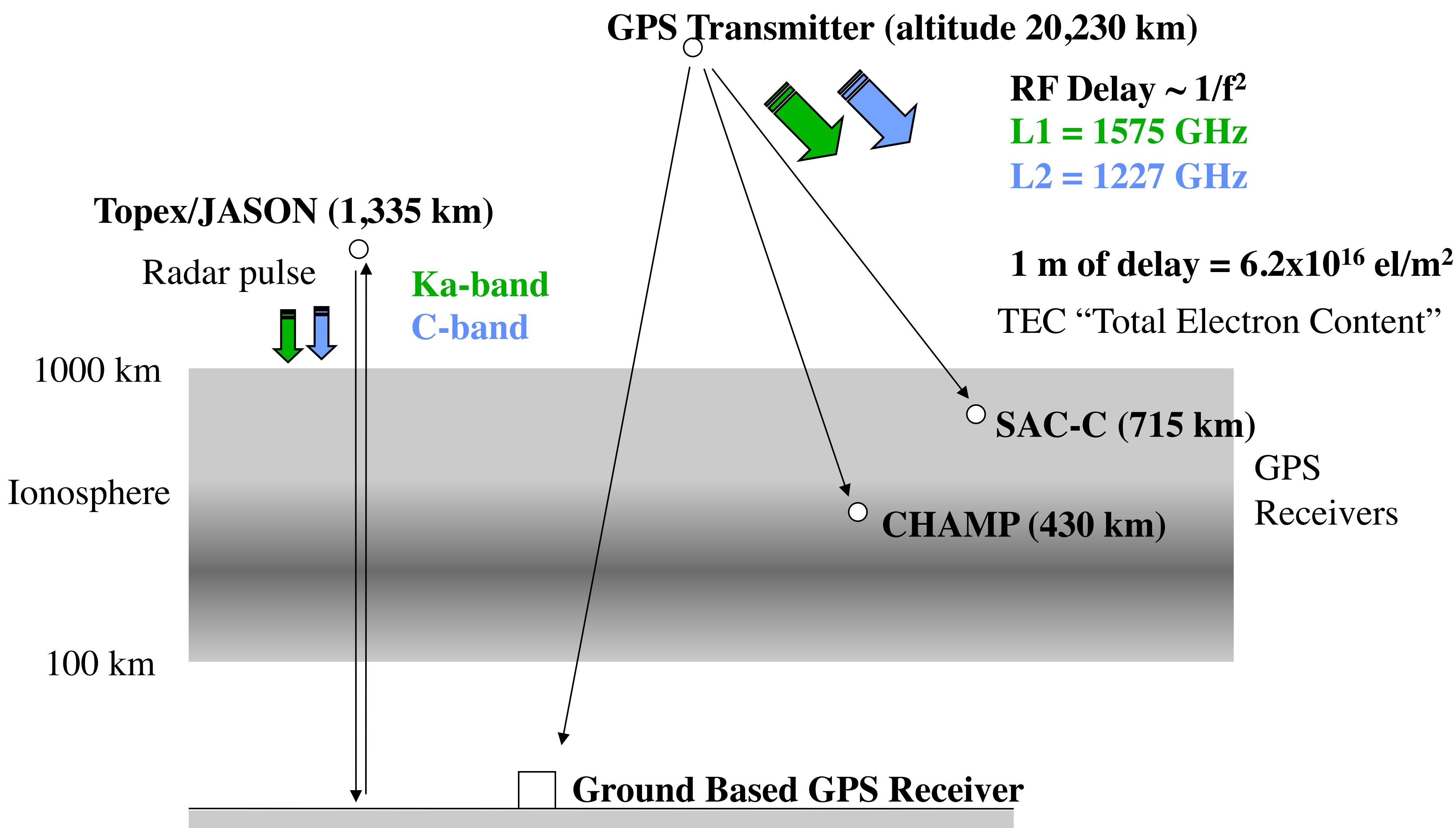
Electron content above 400 km altitude



Mannucci et al., *GRL* 2005

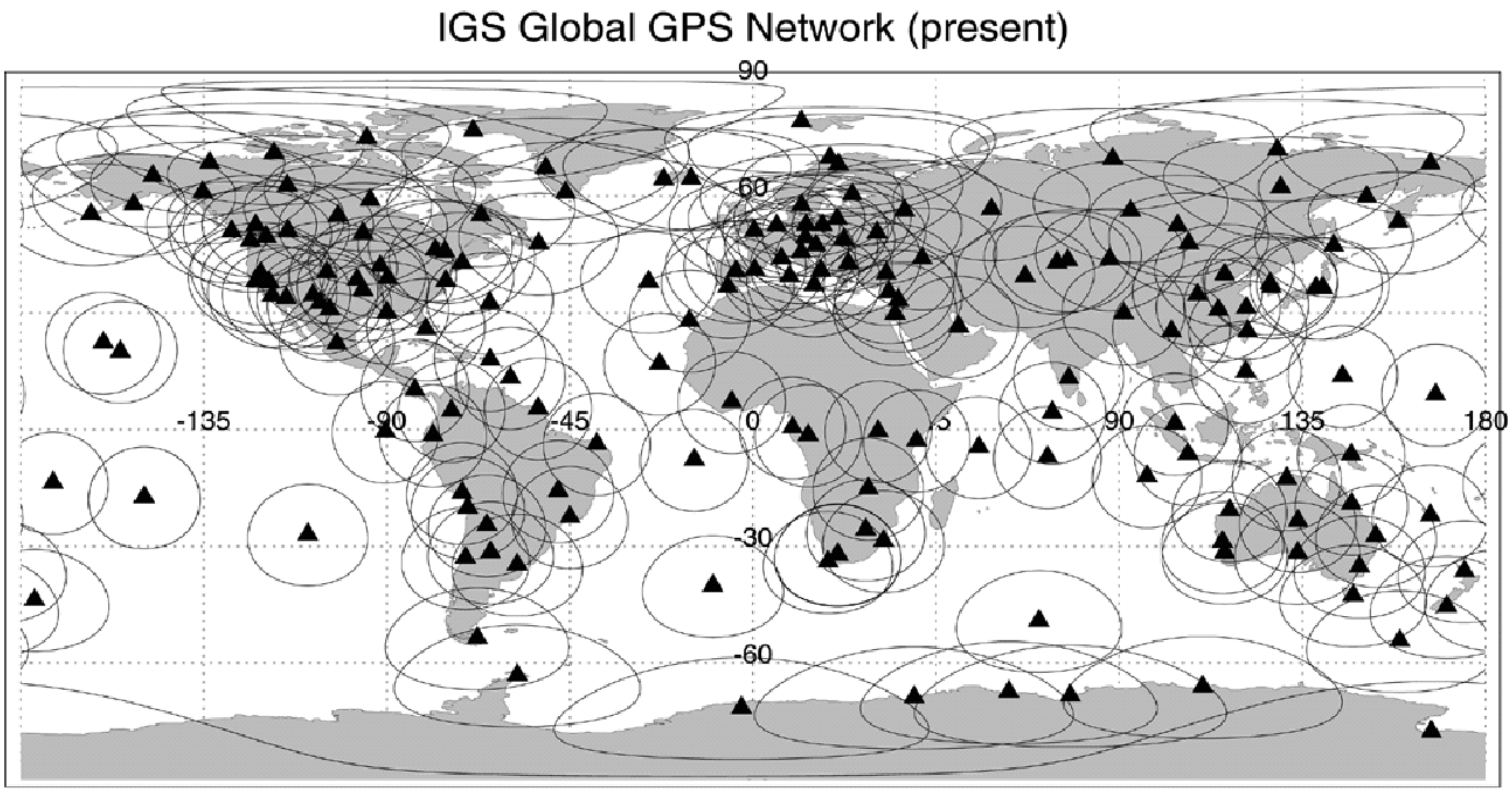
"Global Ionospheric Storm"

Solution: Observations



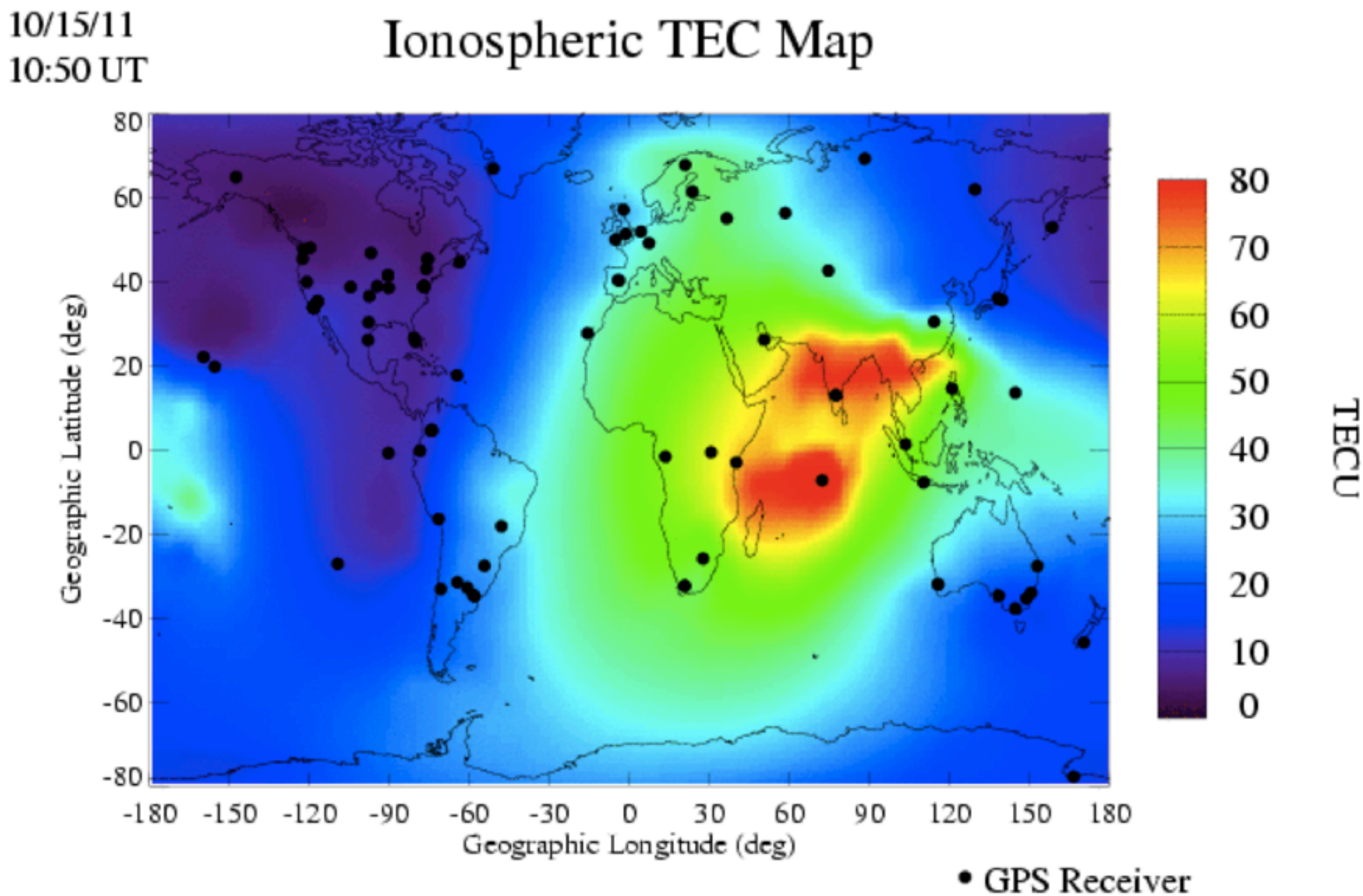
Ground GPS Network: Daily Collection

IGS Global GPS Receiver Network

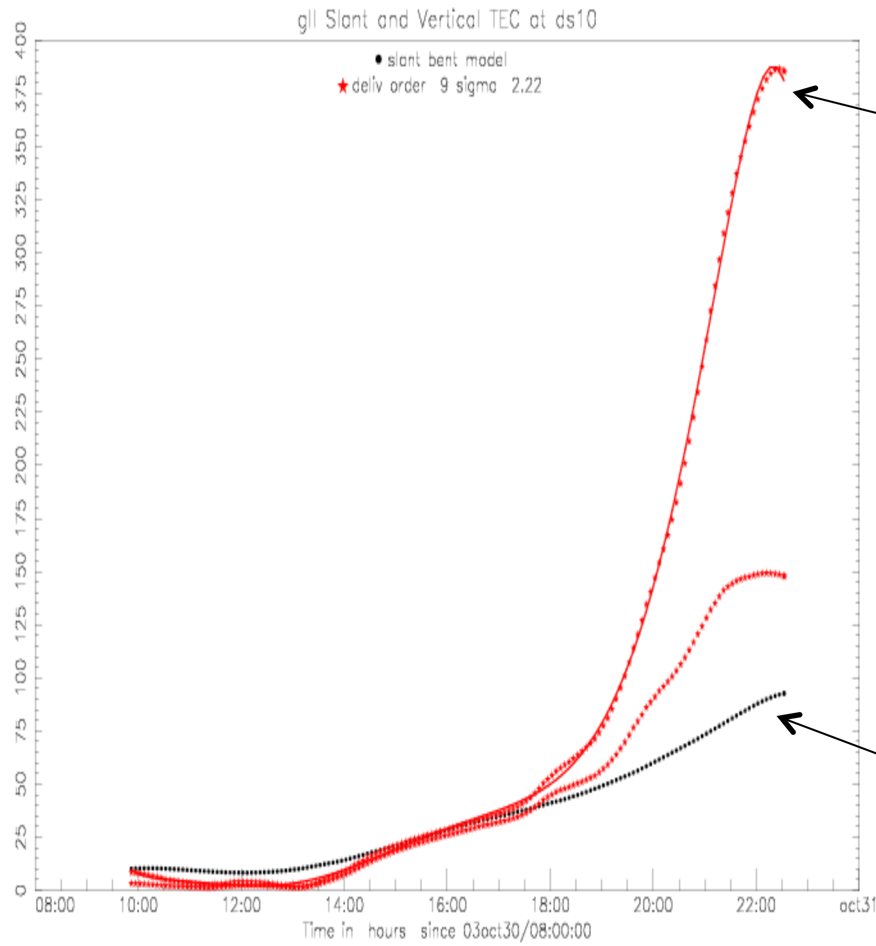


10 degree elevation mask. Subionospheric height at 450 km.

Global Ionospheric Map (Vertical TEC)



Impact of Ionospheric Storms on Tracking Data



Delivered calibration for flight project

Ionospheric "climate"
No data input

Lead: Tom Runge

Civil Aircraft Navigation: Another Space Weather Application

Navigating Aircraft Using GPS (single frequency)

Critical Requirements:

- **Safety-of-life**
- **High availability**
- **Bound ionospheric error to 99.999% certainty**

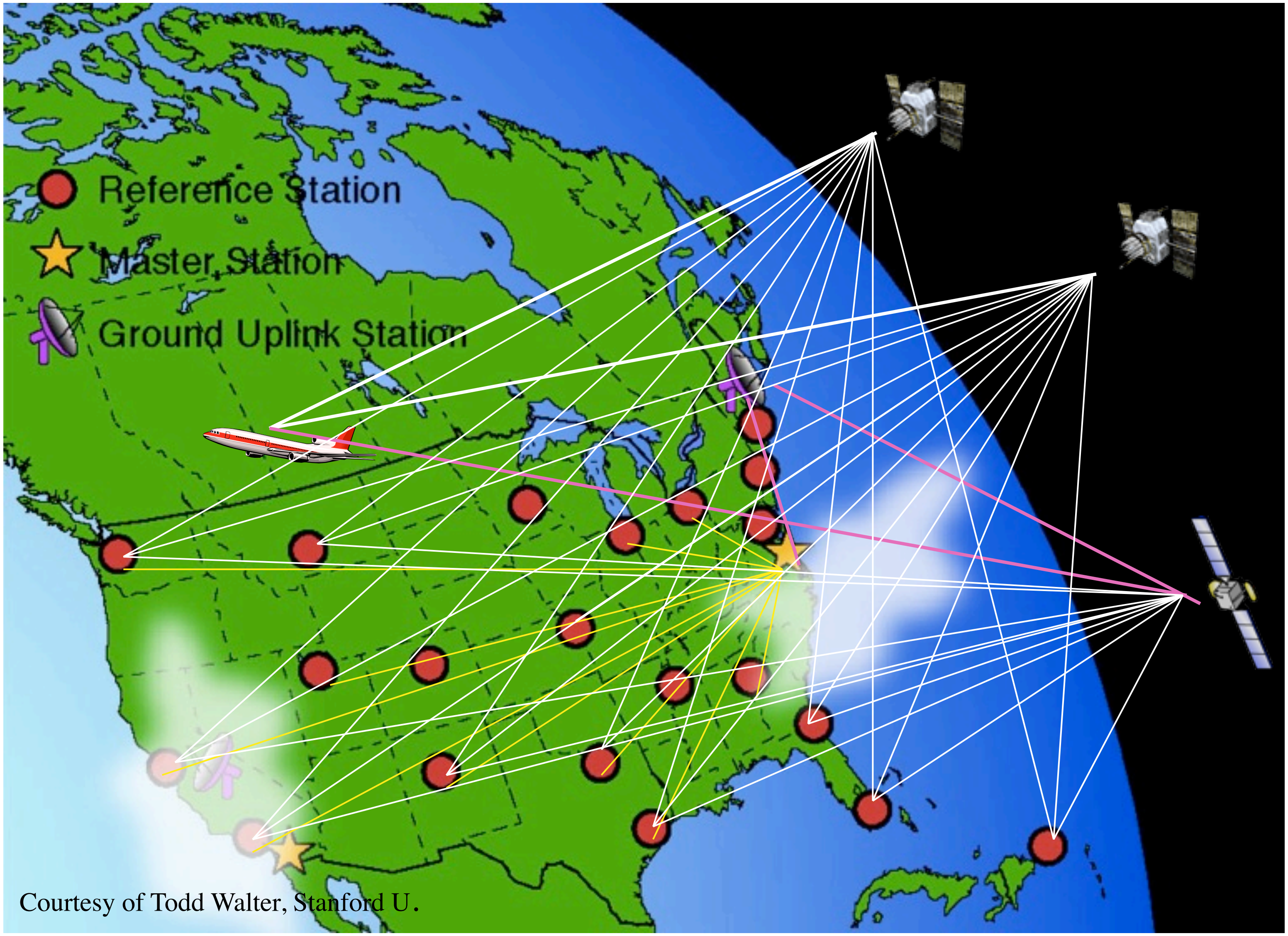
"Extreme Storm Detector"

Deny WAAS ionosphere correction during extreme storms

Without the ESD, margins are not met under the most extreme conditions

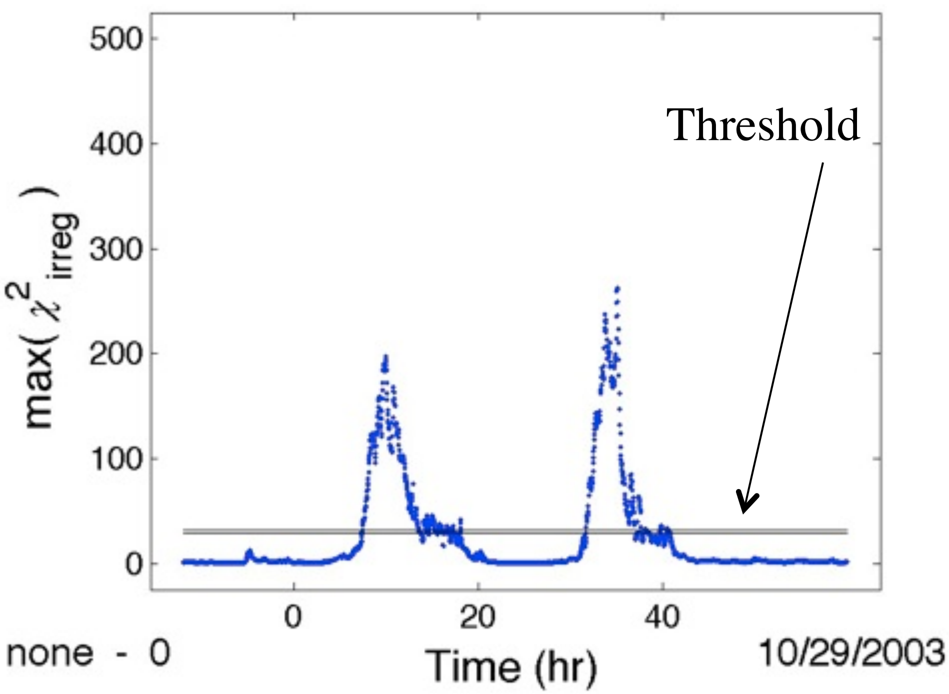
Lead: Larry Sparks

Components of the Wide Area Augmentation System

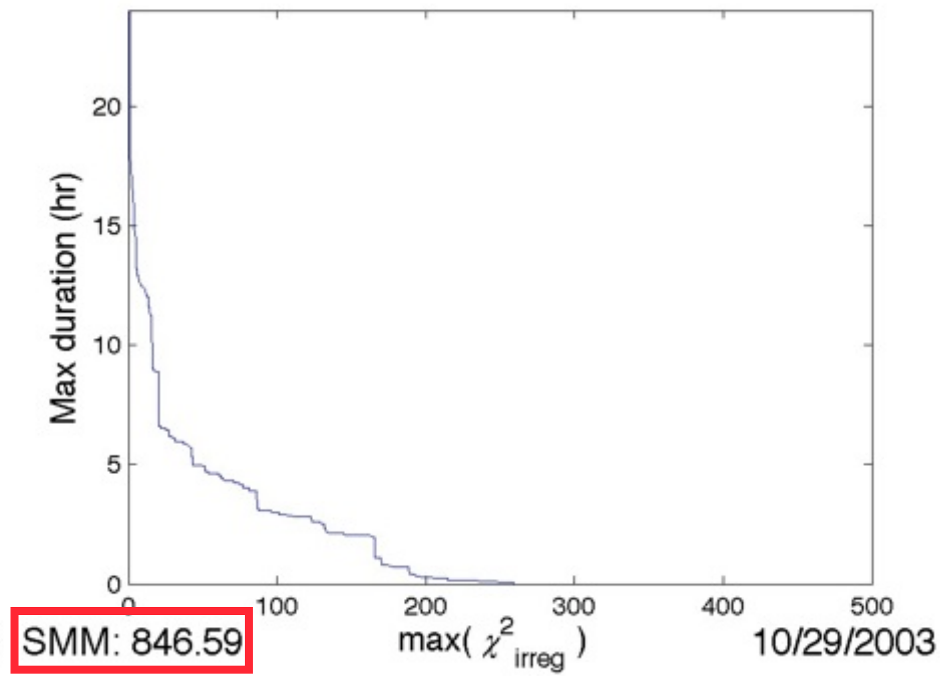


Extreme Storm Detection
October 29-31, 2003

Monitor goodness-of-fit over entire US region

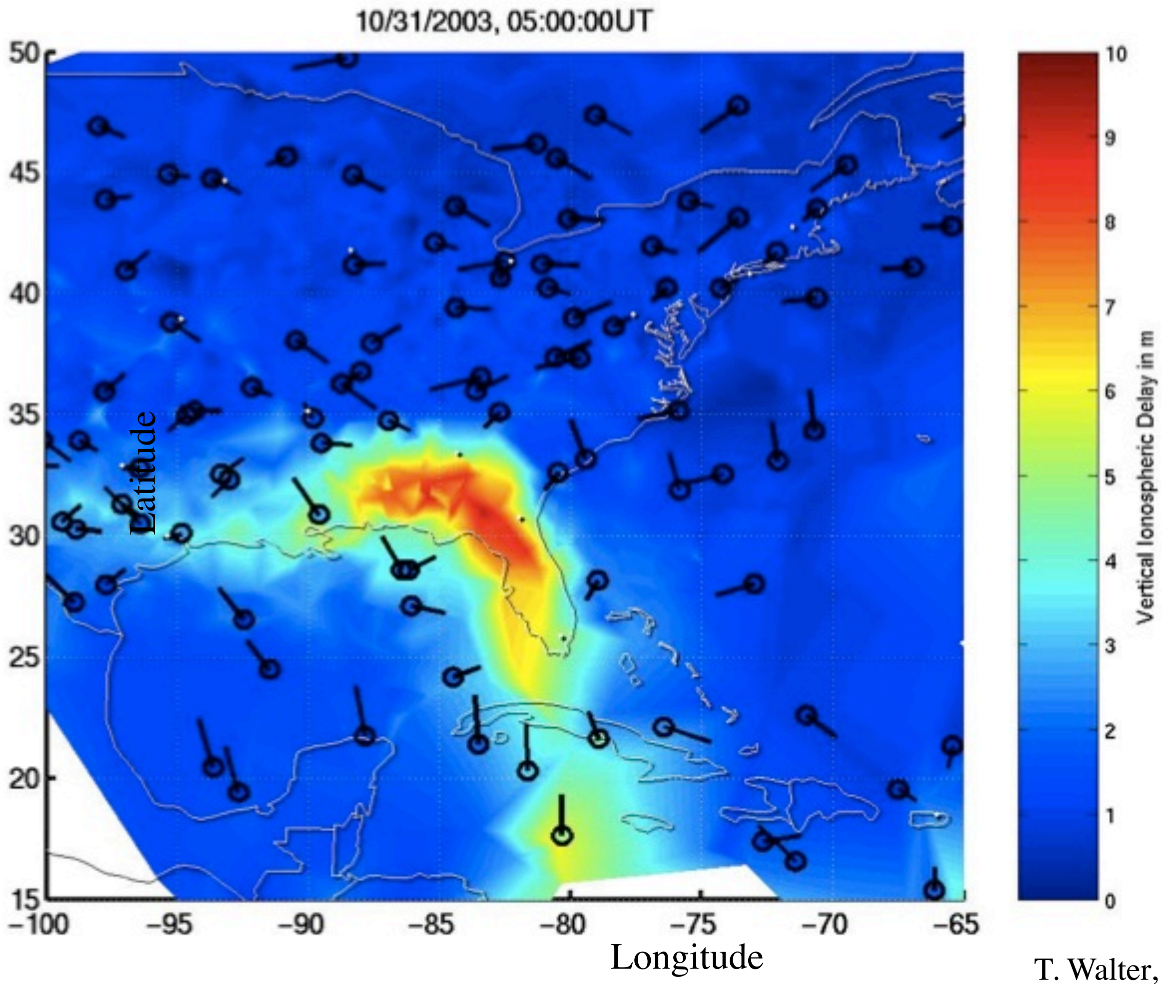


RDM vs. time



Maximum duration above *RDM* vs. *RDM*

The "Threat": Undersampling of a large "irregularity"



T. Walter, Stanford

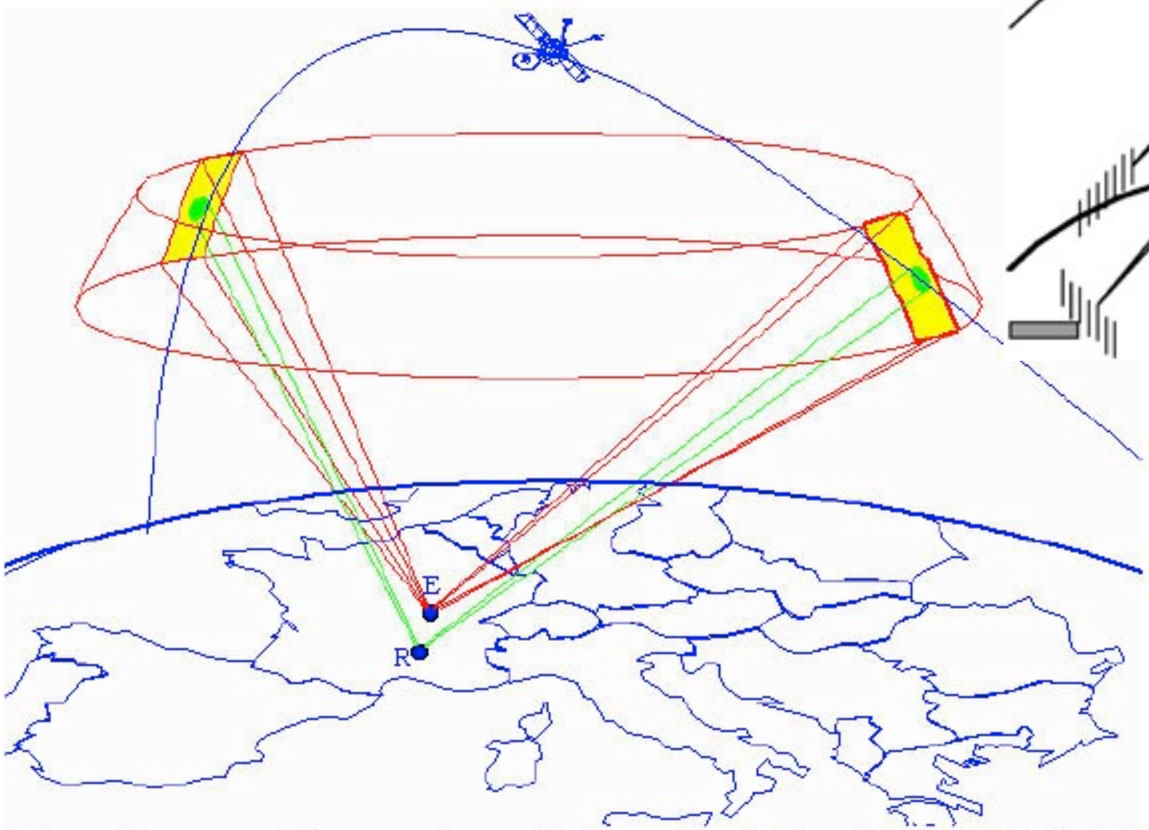
Formed in the aftermath of the large TEC increases

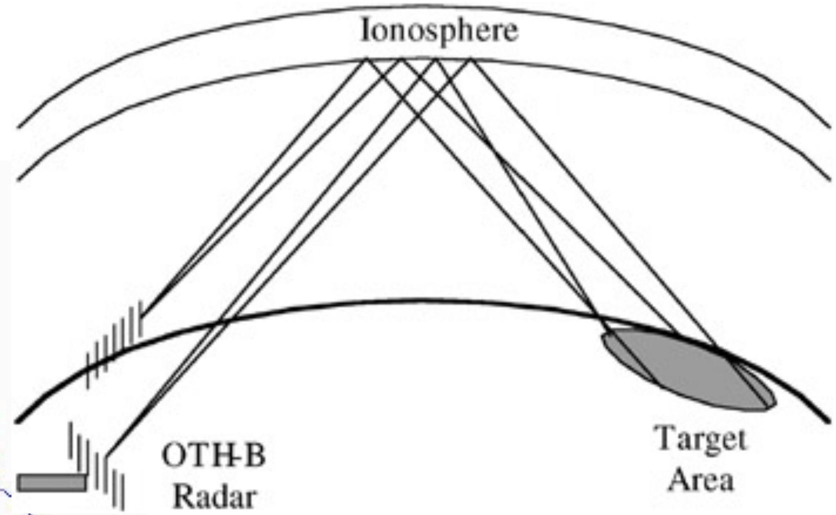
- Science
- Applied Research

Highly localized irregularities in ionospheric TEC represent an integrity threat.
(Note: 5 measurements that sample the irregularity have been removed.)

Radar Applications Affected by Earth's Ionosphere

Satellite within Earth's ionosphere



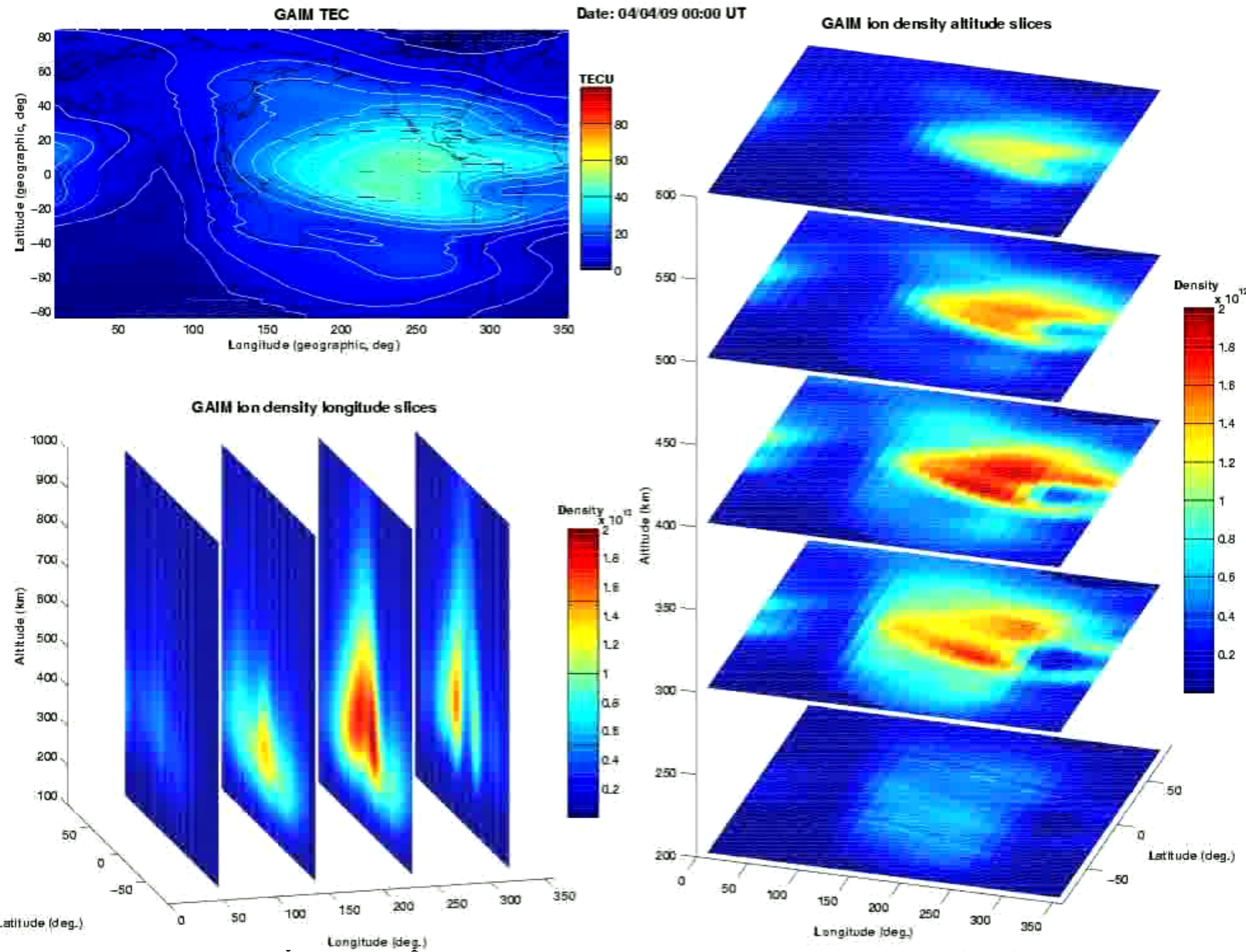


Over-the-Horizon Radar

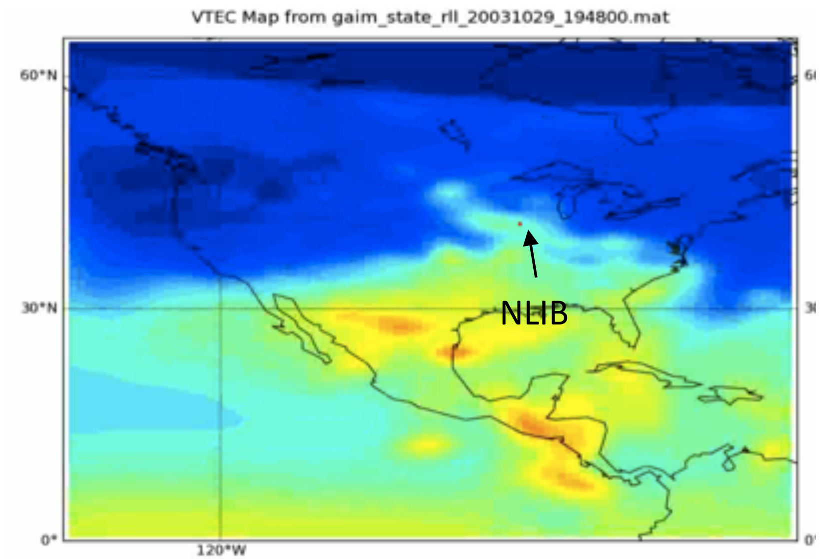
Ionosphere introduces additional signal "range"

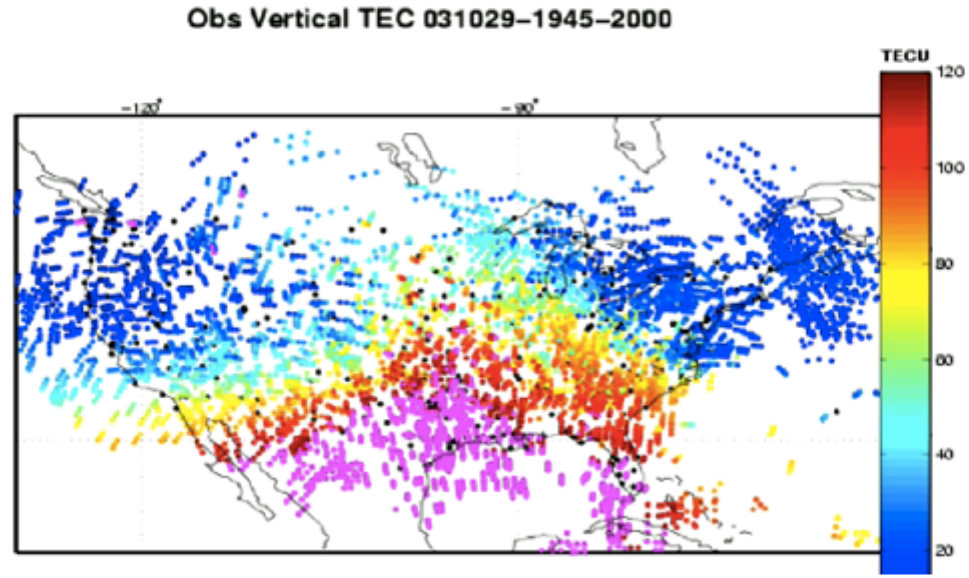
Solution: monitor ionosphere local to the radar site

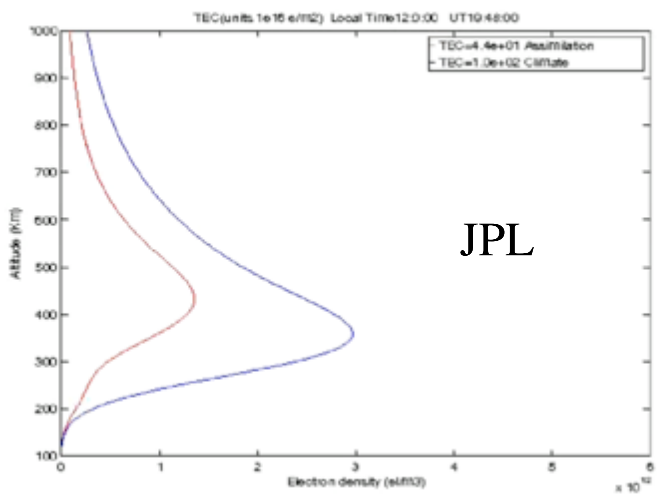
Global Assimilative Ionosphere Model (GAIM): Electron Density Model of the Ionosphere

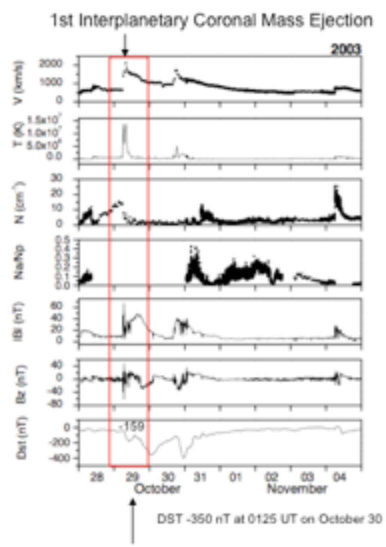


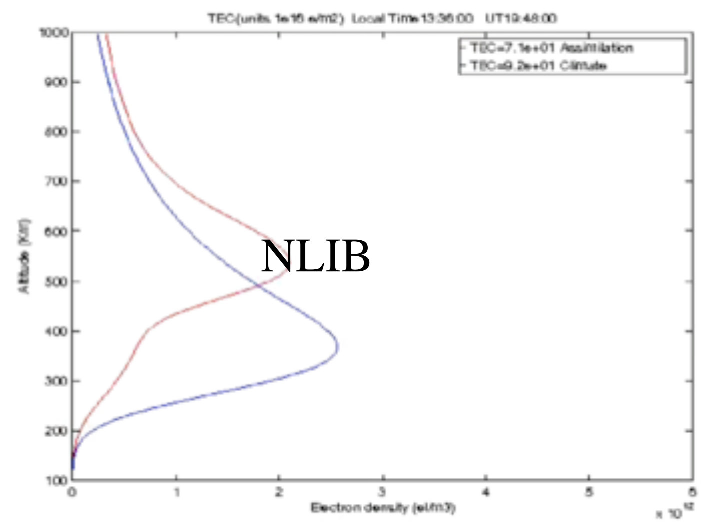
Nested Grid GAIM:
High Spatial Resolution Locally



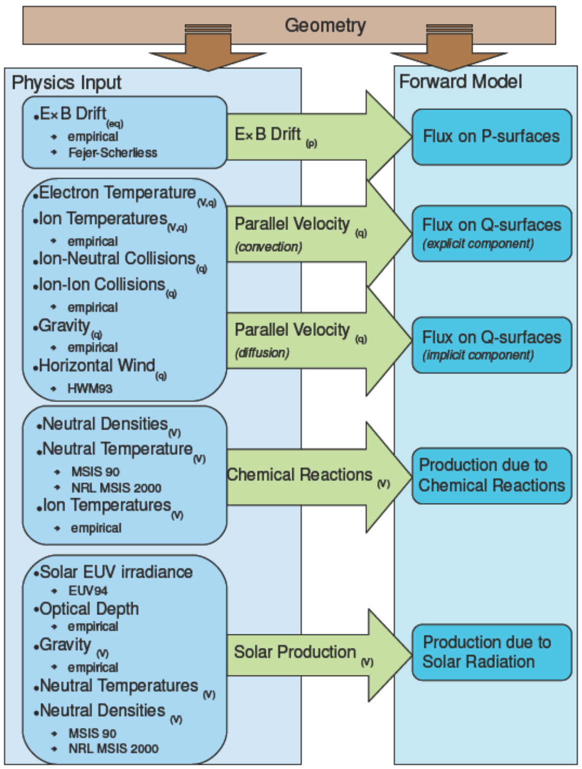




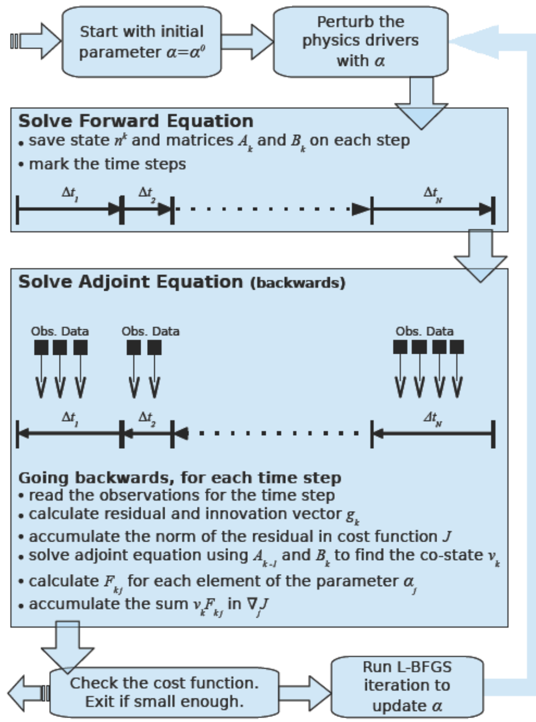




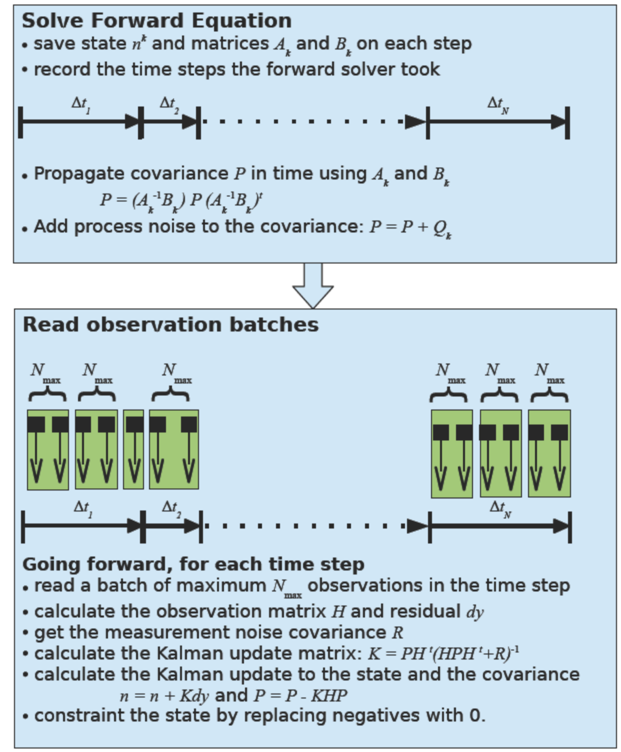
JPL/USC GAIM++: A Numerical Space Weather Prediction Model



Physics-Based Model of the Ionosphere (With Adjoint)



4DVAR



Kalman Filter

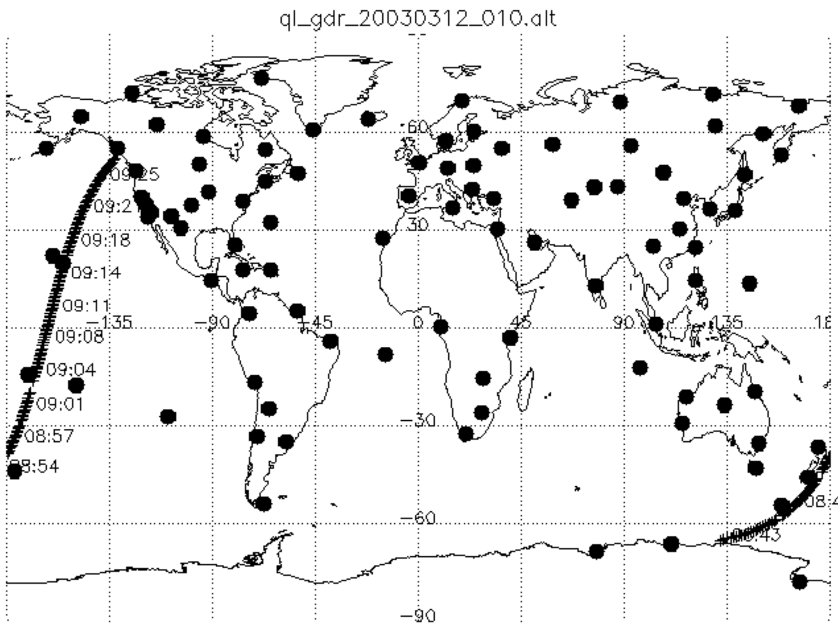
Assimilation Modules

Modify model output based on data

Lead: Phil Stephens

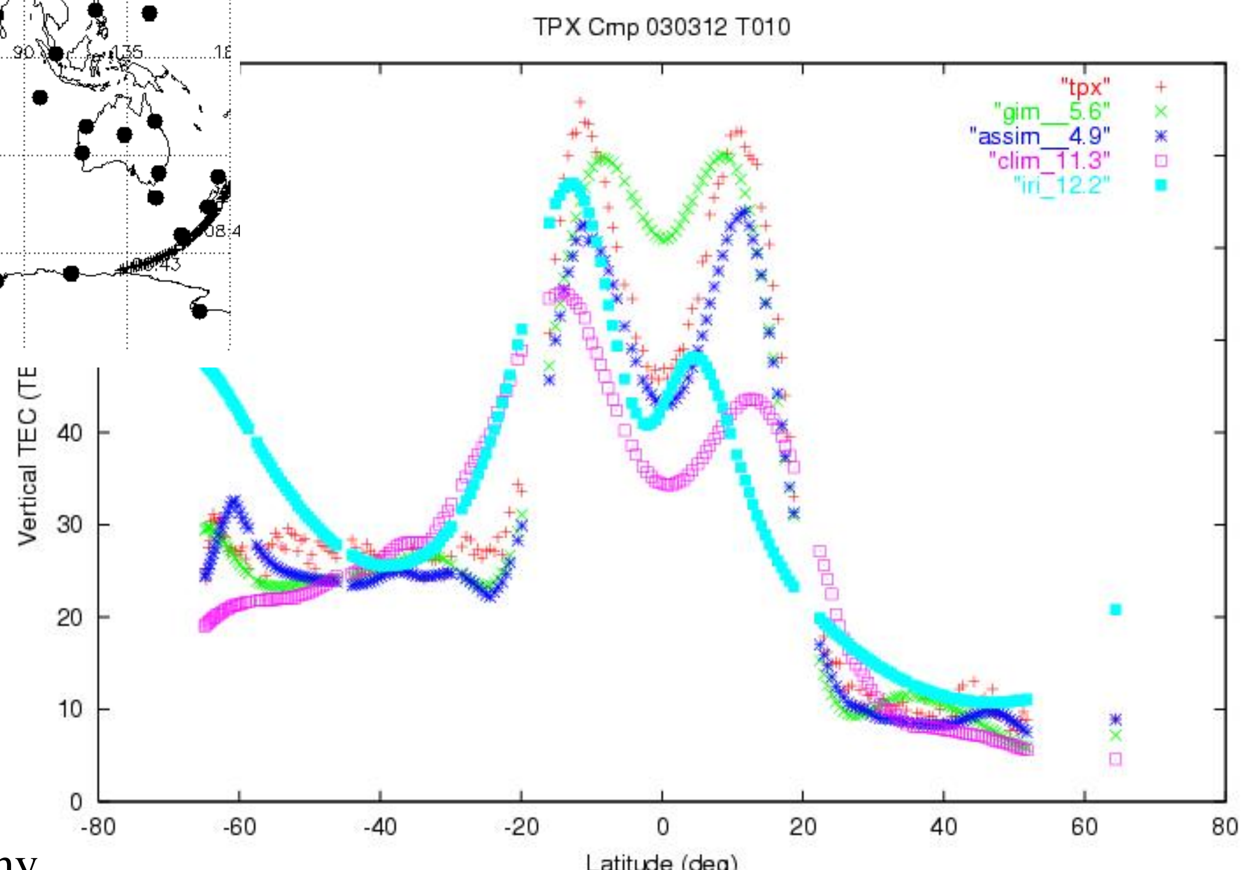
From Vardan Akopian's Ph.D. Thesis, USC

Ocean Altimetry: A Space-Based Radar



TOPEX-JASON series of scientific/operational ocean altimetry satellites (1992-ongoing)

Requirement: cm-level instantaneous precision

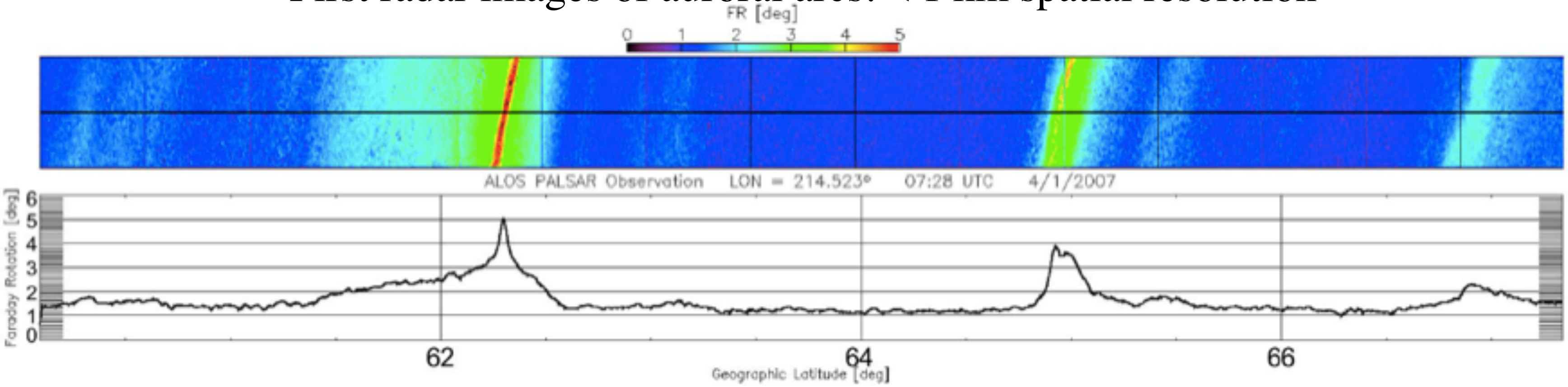


JPL produces the "IONEX" global ionospheric map to support the altimetric community. Available at CDAweb and other archives

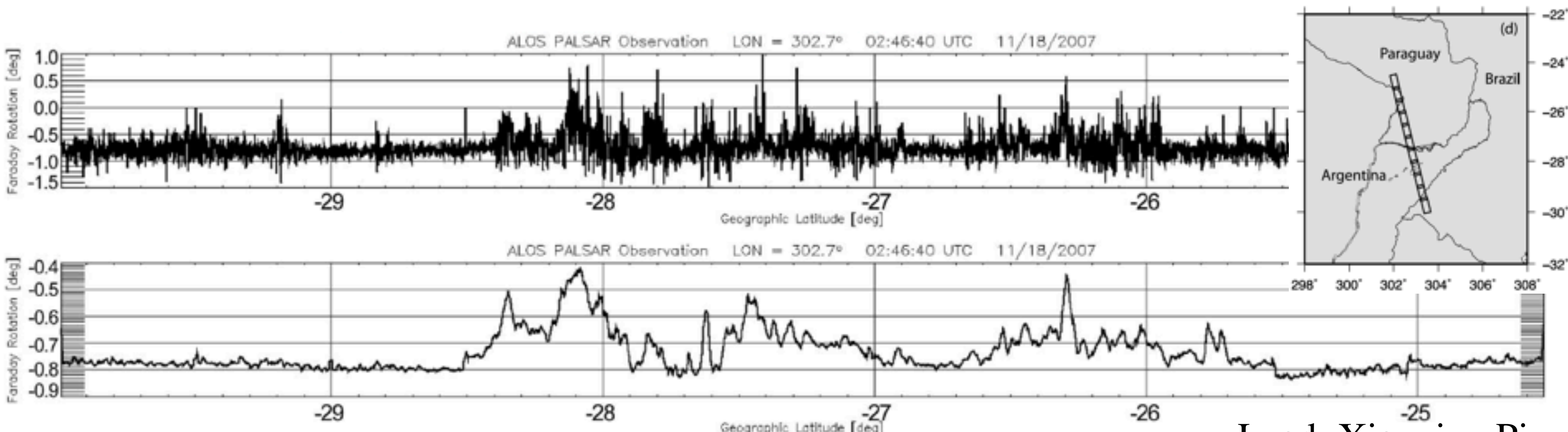
Lead: Attila Komjathy

Synthetic Aperture Space-Based Radar

First radar images of auroral arcs. < 1 km spatial resolution



Low latitude irregularities will corrupt SAR images by “scrambling” signal phase



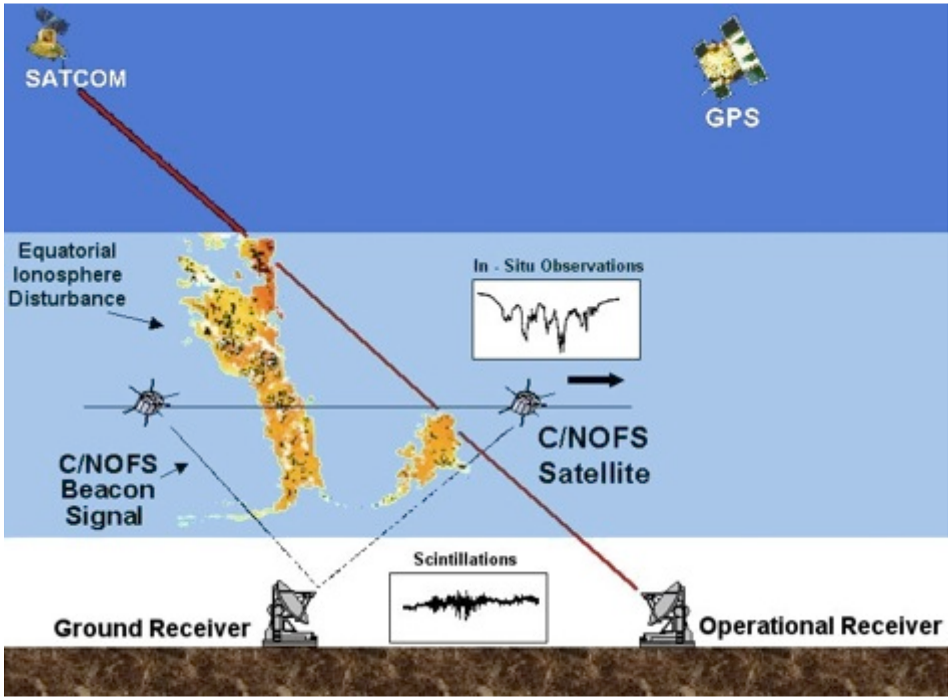
Lead: Xiaoqing Pi

Communications

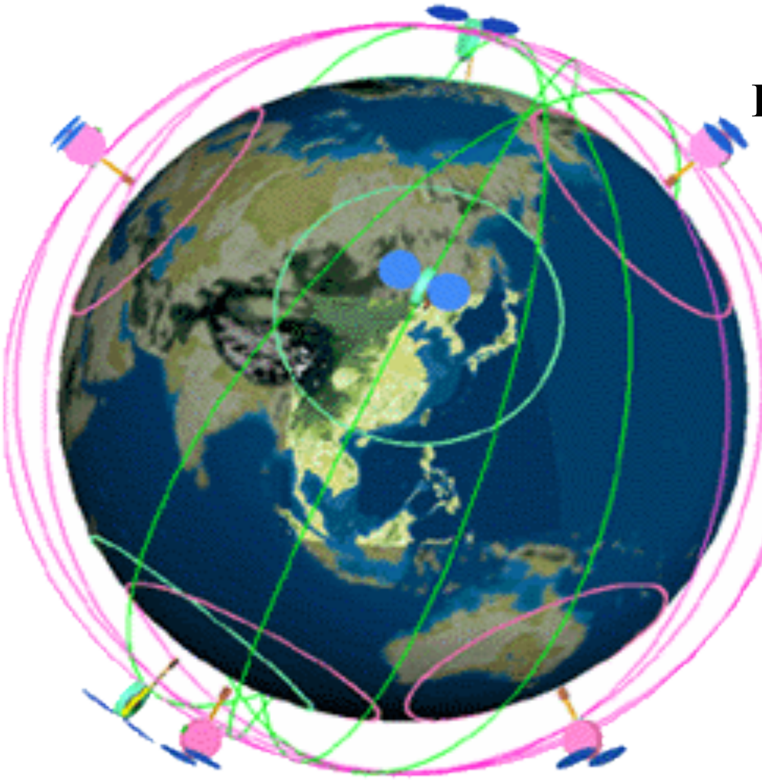
- **Communications are affected by small-scale ionospheric irregularities that cause radio frequency signals to "scintillate"**
- **Air Force maintains a world-wide network of radio beacons to monitor ionospheric conditions**

- **The C/NOFS satellite (Communications/Navigation Outage Forecasting System) provides low-latitude information from a 13° inclination orbit**
- **C/NOFS models determine conditions favorable to formation of irregularities (plasma instability)**

Scintillation affects NAV also

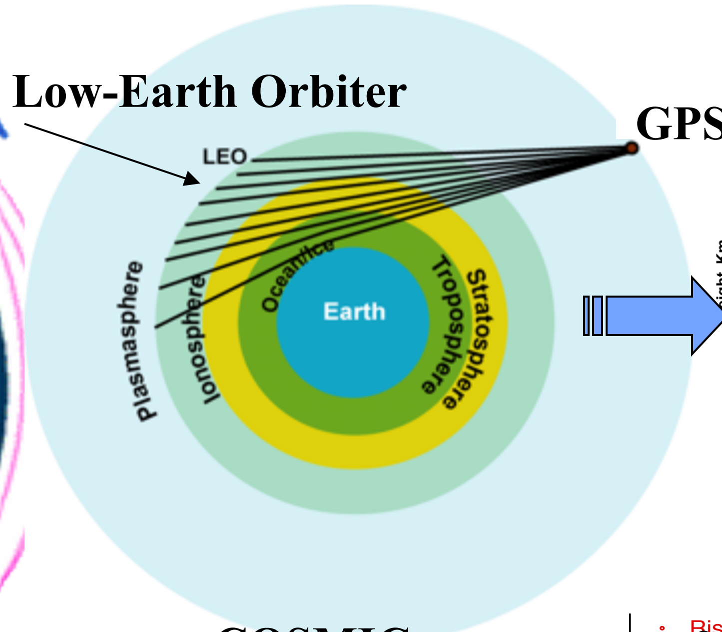


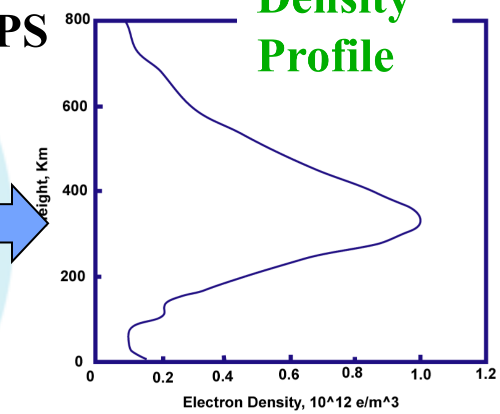
Solution: GPS Receivers in Low Earth Orbit



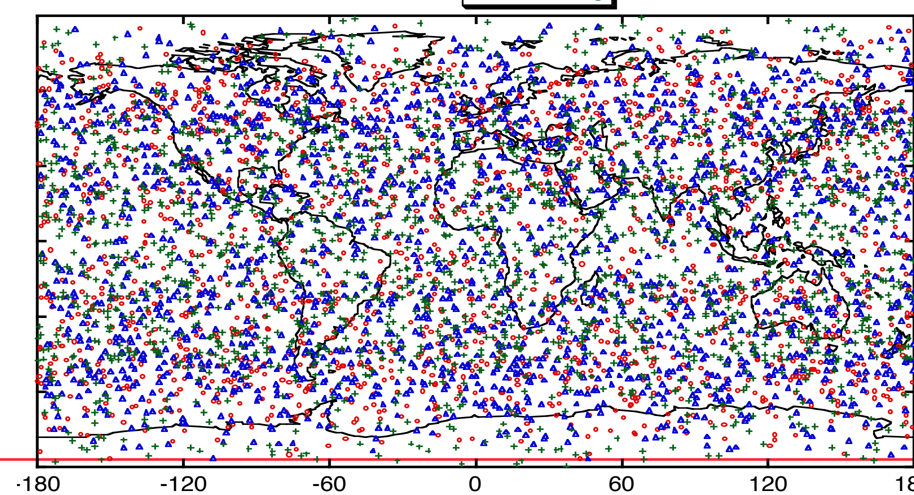
Six-satellite COSMIC constellation
Launched March 2006

NSF NASA USAF NOAA NSPO ONR

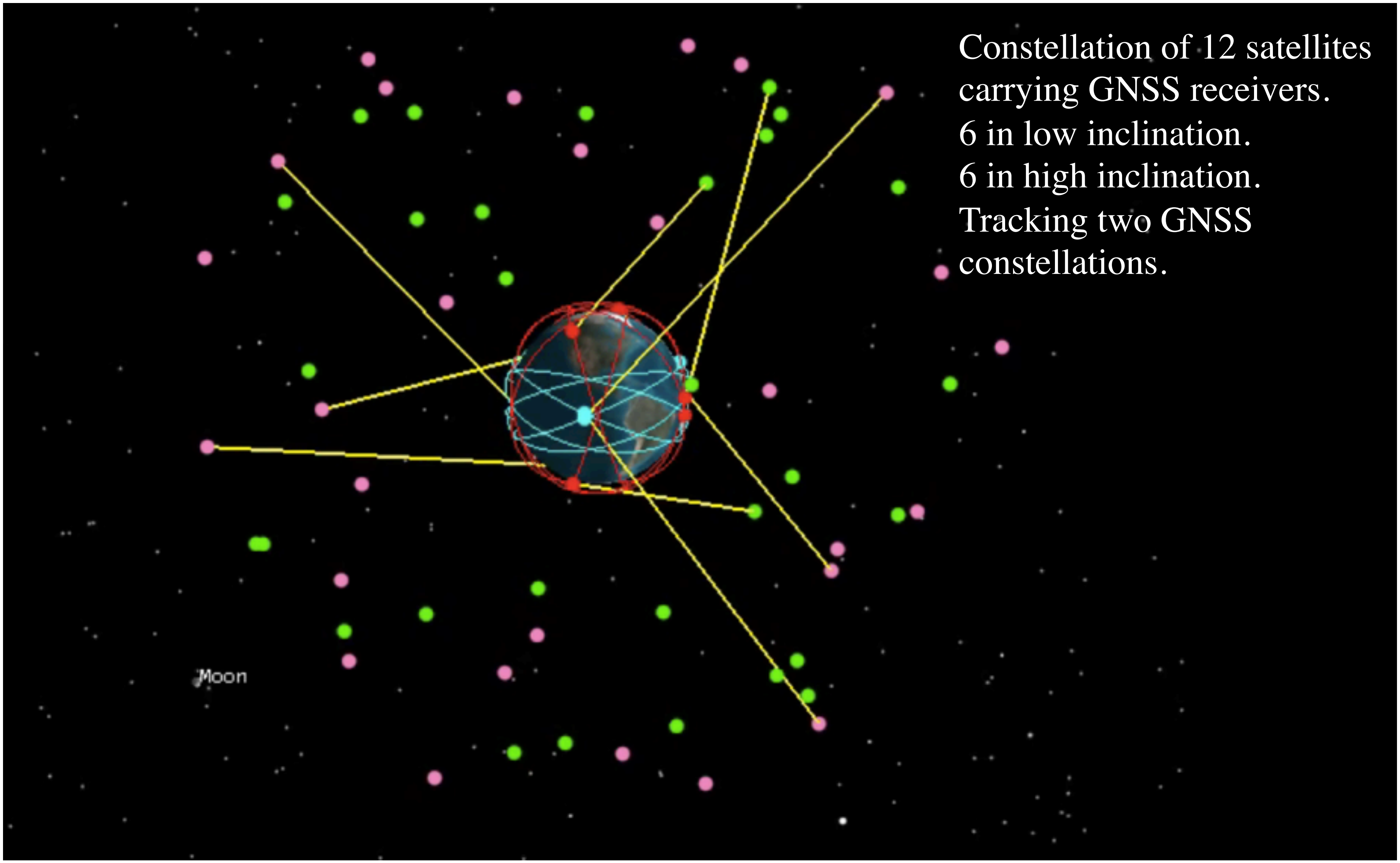




COSMIC coverage ~2500 profiles/day



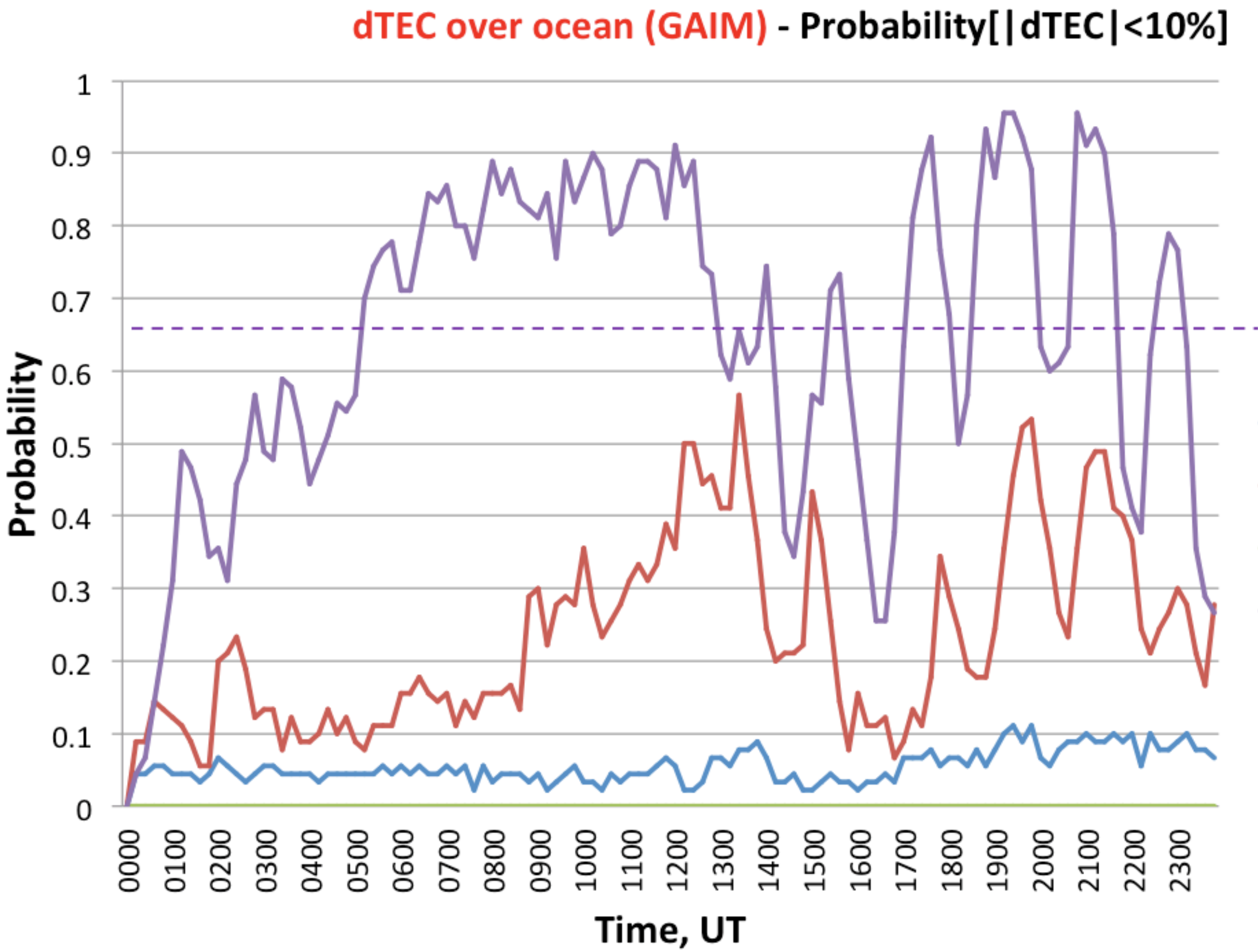
Planned for 2015: COSMIC-2/FORMOSAT-7

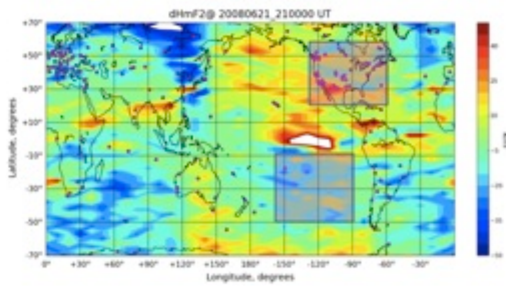


Constellation of 12 satellites carrying GNSS receivers.
6 in low inclination.
6 in high inclination.
Tracking two GNSS constellations.

Understanding Future Benefit: Observation System Simulation Experiment (OSSE)

COSMIC-2 significantly improves nowcasts over ocean regions





Summary (1)

- **We have summarized the challenges of *nowcasting*: estimating how applications are affected by ionospheric conditions based on limited data from a “different” time and place**
- ***Forecasting* represents another formidable challenge to estimate impact hours to days in advance**
- **GPS-based observations from ground and space are essential**
- **DISCOVR is essential for science, provides 1 hour lead time**
  - **Follow on the ACE satellite measuring solar wind at L1**
- **Solar monitoring essential for 1-2 day lead times**

Summary (2)

- **Meeting the space weather challenge requires investments in both science and applied research**
- **Near real-time observing network must be maintained and increased**
  - **Not shown: continuous validation of the model output**
- **Improvements to nowcasting and forecasting require dedicated efforts combining both the purely scientific endeavor to understand and the developments of models and techniques to create products for users**